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Hallett

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(54) **METHOD AND SYSTEM TO IDENTIFY A POSITION OF A MEASUREMENT POLE**

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G06T 7/00	(2006.01)
G01C 15/06	(2006.01)
G06F 3/03	(2006.01)

(52) **U.S. Cl.**

CPC ***G06T 7/0057*** (2013.01); ***G01C 15/06*** (2013.01); *G06F 3/0325* (2013.01); *G06T 2207/10004* (2013.01); *G06T 2207/10028* (2013.01); *G06T 2207/30204* (2013.01)

(58) **Field of Classification Search**

USPC 382/106, 154

See application file for complete search history.

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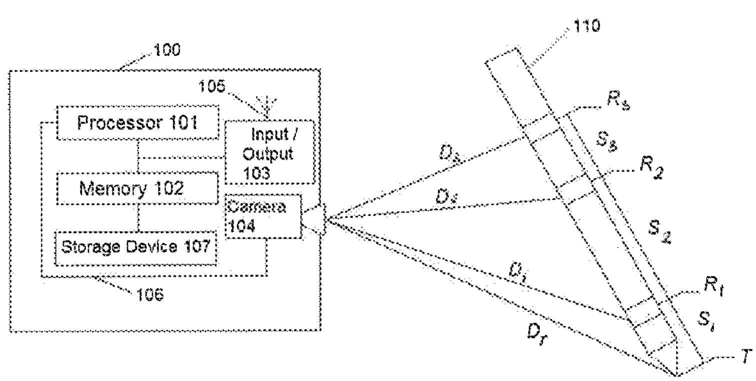
(57) **ABSTRACT**

A method and a system in which an image of an object having a tip end and a plurality of markings disposed on an outer surface is acquired, a distance between the measurement system and each of the plurality of markings and a plurality of angles at which the object is positioned in the three-dimensional space are determined, a three-dimensional vector of the object is determined based on the distance between the measurement system and each of the plurality of markings and based on the plurality of angles at which the object is positioned in the three-dimensional space, and a position of the tip end in the three-dimensional space is determined based on the distance to each of the plurality of markings and based on the three-dimensional vector of the object.

20 Claims, 3 Drawing Sheets



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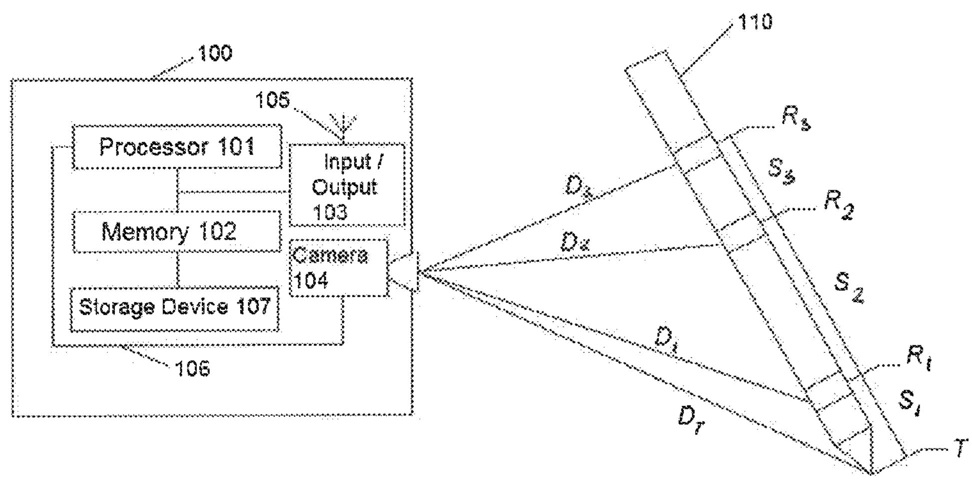
100
105
Processor 101
Input / Output 103
Memory 102
Camera 104
Storage Device 107
106
110
R_3
S_3
R_2
S_2
R_1
S_1
T
D_3
D_2
D_1
D_T

Fig. 1

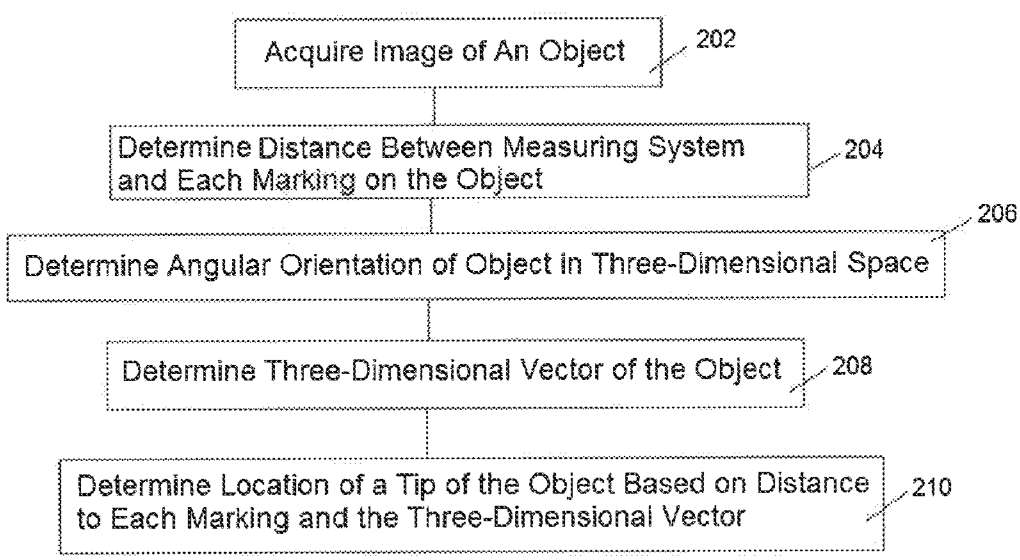
Acquire Image of An Object
202
Determine Distance Between Measuring System and Each Marking on the Object
204
Determine Angular Orientation of Object in Three-Dimensional Space
206
Determine Three-Dimensional Vector of the Object
208
Determine Location of a Tip of the Object Based on Distance to Each Marking and the Three-Dimensional Vector
210

Fig. 2

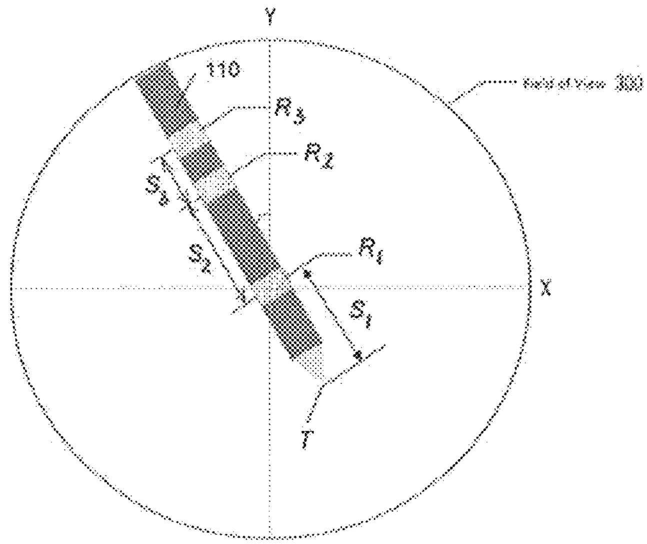

Fig. 3

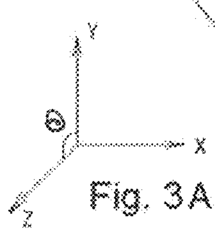

Fig. 3A

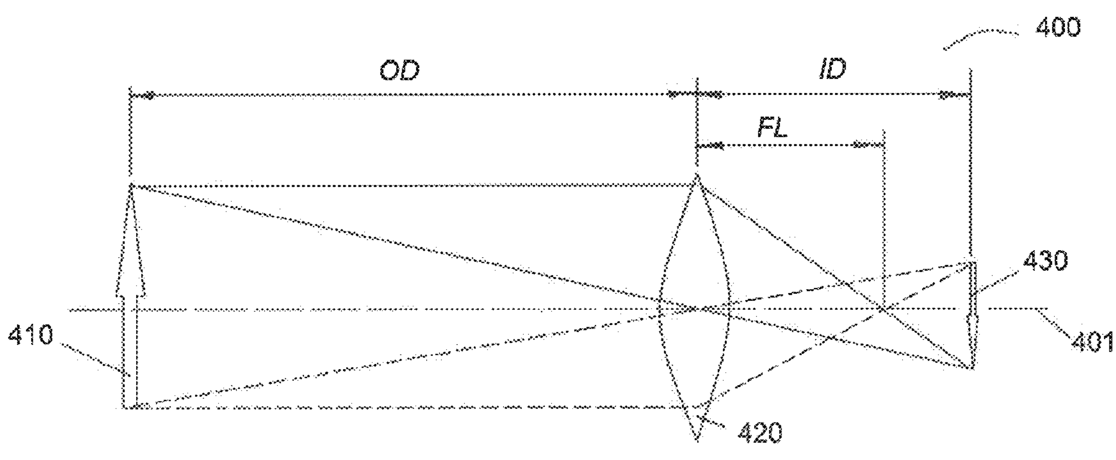

Fig. 4

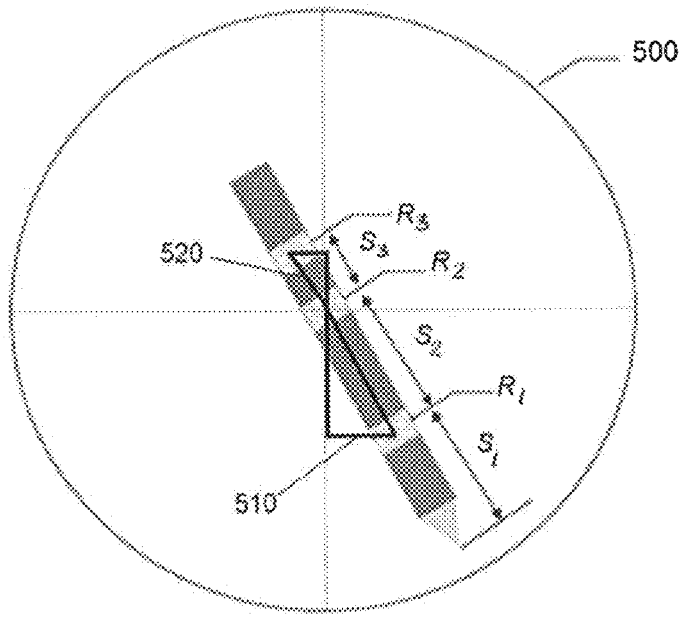
500
R3
S3
520
R2
S2
R1
S1
510

Fig. 5

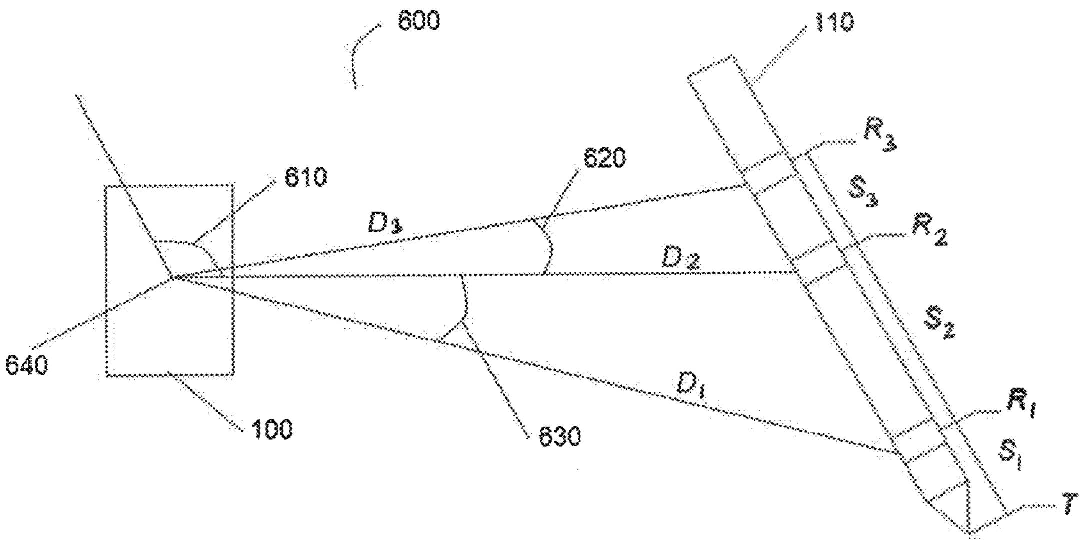
600
110
R3
610
620
D3
S3
R2
D2
S2
640
D1
R1
100
630
S1
T

Fig. 6

METHOD AND SYSTEM TO IDENTIFY A POSITION OF A MEASUREMENT POLE

BACKGROUND

The present disclosure relates to a measurement system for determining a position of an object or a portion of the object, and to a corresponding measurement method.

The determination of a location of an object, its position, velocity, vector, etc., is normally very costly as it requires complex and expensive equipment. It is especially true in the case of moving objects as it is difficult or even impossible to determine a position of an object or a position of a portion of the object if the object is in motion.

BRIEF SUMMARY OF THE INVENTION

The present disclosure relates to providing a measurement system and measurement method with which a determination of a location of a tip of an object can be undertaken accurately, rapidly, and with a very high degree of automation. In one embodiment, the measurement method is directed to receiving an image of an object. The object is a rod which has a tip end and a plurality of markings disposed on an outer surface of the object. In an embodiment, the markings are photo-reflectors (e.g., reflective tape), optical signal emitters, or a combination thereof. A distance between the tip end and at least one of the plurality of markings and a distance between each of the plurality of markings are known.

Upon receiving the image of the object, a distance between the measurement system and each of the plurality of markings is determined. The measurement method is also directed to determining a three-dimensional vector of the object. A process of determining the three-dimensional vector of the object includes determining a yaw angle at which the object is positioned in the three-dimensional space and determining a pitch angle at which the object is positioned in the three-dimensional space.

The method is further directed to determining a position of the tip end in the three-dimensional space based on the determined distance to each of the plurality of markings and based on the determined three-dimensional vector of the object in the three-dimensional space. The method is also directed to transmitting the image of the object to a remote device and displaying to a user the position of the tip end of the object, the distance to each of the plurality of markings, and the three-dimensional vector of the object.

These and other advantages of the invention will be apparent to those of ordinary skill in the art by reference to the following detailed description and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a schematic representation of a measurement system in use according to an embodiment;

FIG. **2** illustrates a flowchart showing a method according to an embodiment;

FIGS. **3** and **3A** illustrate an image of an object in a field of view of a measurement system according to an embodiment;

FIG. **4** illustrates generation of an image of object **110** by measurement system **100** according to an embodiment;

FIG. **5** illustrates graphical representation of determining horizontal and vertical angles of object **110** in three-dimensional space according to an embodiment; and

FIG. **6** illustrates a graphical representation **600** of determining slope distance according to an embodiment.

DETAILED DESCRIPTION

FIG. **1** illustrates a schematic representation of a measurement system **100** to determine a position of tip T of object **110** according to an embodiment. Specifically, FIG. **1** illustrates a measurement system **100** which includes a processor **101**, a memory **102**, an input-output module **103**, a camera **104**, antenna **105**, electrical/electronic circuitry **106**, and storage device **107**.

Processor **101** may be any suitable processor, computing module, data processing device, or combination of the same. Processor **101** is communicatively coupled with memory **102** and with a storage device **107** for storing computer-readable program instructions that provide the governing logic for controlling processor **101** to execute computer-readable program instructions stored in storage device **107** or other computer readable medium to determine a position of tip T of object **110** by tracking movement of one or more prisms, determining horizontal angles around the vertical axis and vertical angles at which object **110** is positioned in three-dimensional coordinate plane.

Processor **101** may include both general and special purpose microprocessors, and may be the sole processor or one of multiple processors of measurement system **100**. Processor **101** may comprise one or more central processing units (CPUs), for example. Processor **101** and memory **102** may include, be supplemented by, or incorporated in, one or more application-specific integrated circuits (ASICs) and/or one or more field programmable gate arrays (FPGAs).

Storage device **107** and memory **102** each comprise a tangible non-transitory computer readable storage medium. Data storage device **107** and memory **102**, may each include high-speed random access memory, such as dynamic random access memory (DRAM), static random access memory (SRAM), double data rate synchronous dynamic random access memory (DDR RAM), or other random access solid state memory devices, and may include non-volatile memory, such as one or more magnetic disk storage devices such as internal hard disks and removable disks, magneto-optical disk storage devices, optical disk storage devices, flash memory devices, semiconductor memory devices, such as erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), compact disc read-only memory (CD-ROM), digital versatile disc read-only memory (DVD-ROM) disks, or other non-volatile solid state storage devices.

Input-Output module **103** is a module which includes input means, such as a keypad, touchscreen, haptic controls, voice-recognition means and the like, used to identify user command input, for example to direct camera **104** toward object **110** and to request determination of a distance to object **110**, calculation of angles at which object **110** is positioned in a three-dimensional coordinate plane, and determination of a position of object **110** or a portion thereof (e.g., tip T of object **110**). Input-Output module **103** also includes an output means, such as a display or a monitor to output images of object **110**, indicate an input command from a user, and display results of calculation of distance to each marking on object **110**, including a position of a tip of object **110** based on calculation of distances to each marking of object **110**.

Camera **104** can be a video camera. In an embodiment, camera **104** is a matrix Charge-Coupled Device (CCD) camera which provides a direct access of processor **101** to an acquired image of object **110**. In an embodiment, camera **104** is configured to capture images of the markings of object **110** and identify a center of object **110** for tracking a measuring. A method of operation of CCD cameras is well known in the art and therefore is not described herein.

It is to be understood that design of measurement system **100** as described above is presented for purposes of illustration and not of limitation and that the invention described herein can be practiced by other than the described embodiments of measurement system **100**. For example, measurement system **100** may include data transmitting means, such as antenna **105** to transmit received images of object **110** to a remote storage device or to a remote processor (not shown in FIG. **1**) in order to carry out determination of a position of object **110** or a portion thereof in a three-dimensional coordinate plane and to display the determined position of object **110** in a remote output means.

Measurement system **100** may also include a power source (not shown) to supply power to measurement system **100**. It is to be understood that measurement system **100** also includes electronic and electrical circuitry **106** to enable communicative connectivity between the elements of measurement system **100** and to synchronize the line-scanning frequency or image-scanning frequency of camera **104** (i.e., CCD camera).

In an embodiment, object **110** is a pole which terminates at one end with a tip T and which has at least three markings R_1, R_2, R_3 disposed on a surface at known spacing, i.e., a distance between tip T and each marking R_1, R_2, and R_3 is known. For example, distance between tip T and marking R_1 is distance S_1, distance between marking R_1 and marking R_2 is distance S_2, distance between marking R_2 and marking R_3 is distance S_3. In an embodiment, distance between tip T and marking R_2 equals a sum of distance S_1 and distance S_2. Distance between tip T and marking R_3 equals a sum of distance S_1, distance S_2, and distance S_2.

In an embodiment, each marking is a reflector which is capable of reflecting back an optical signal, with a low degree of scatter, substantially in the direction from which it comes. In other embodiments, each marking is an optical signal emitting element capable of emitting an optical signal, with a low degree of scatter, substantially in any direction.

FIG. **2** illustrates a flowchart showing a measurement method **200** according to an embodiment. The steps of exemplary measurement method of FIG. **2** can be defined by the computer program instructions stored in memory **102** and/or data storage device **107** and controlled by processor **101** executing the computer program instructions. Accordingly, by executing the computer program instructions, the processor **101** executes an algorithm defined by the method steps of FIG. **2**.

Measurement method **200** can be used to determine a location of object **110** using measurement system **100** of FIG. **1**. At step **202**, an image of object **110** is received via image acquisition module **104** of FIG. **1**. In an embodiment, step **202** includes setting up and positioning measurement system **100** at known three-dimensional coordinates. The height to the intersection of the vertical and horizontal axis of measurement system **100** is measured from the known three-dimensional coordinates, along a plumb line from said coordinates to the said intersection of the vertical and horizontal axis of measurement system. A horizontal plane of measurement system **100** is oriented to a secondary known point with three-dimensional coordinates, or to a known azimuth direction. It is to be understood that the height of the measurement system can be zero.

FIG. **3** illustrates an image of object **110** in a field of view of measurement system **100** as received by image acquisition module **104**.

Field of view **300** of measurement system **100** captures an image of object **110** having a tip T and three markings R_1, R_2, and R_3 disposed on a surface at known spacing, i.e., a distance between tip T and each marking R_1, R_2, and R_3 is known. For example, distance between tip T and marking R_1 is distance S_1, distance between marking R_1 and marking R_2 is distance S_2, distance between marking R_2 and marking R_3 is distance S_3. In an embodiment, distance between tip T and marking R_2 equals a sum of distance S_1 and distance S_2. Distance between tip T and marking R_3 equals a sum of distance S_1, distance S_2, and distance S_3.

In an embodiment, field of view **300** also includes coordinate axes where a vertical axes Y and a horizontal axes X are illustrated as a “crosshair” with a third axes (e.g., axes Z), as shown in FIG. **3**A, being perpendicular to each of the vertical axes Y and the horizontal axes X.

Returning to FIG. **2**, at step **204**, a distance between measurement system **100** and each of markings R_1, R_2, and R_3 is determined. In an embodiment, at step **204**, a distance between measurement system **100** and a center of object **110** (not shown) is also determined. FIG. **4** illustrates generation of an image of object **110** by measurement system **100** based on determined center of object **110**. In an embodiment, measurement system **100** measures distance OD between a prism **420** and a center of object **110** based on known focal length FL between prism **420** and a focal point and based on known image distance ID between prism **420** and a generated image **430** of object **110**.

Applying step **204** to FIG. **1**, a determination is made of distance D_1 between marking R_1 and camera **104**, distance D_2 between marking R_2 and camera **104**, and distance D_3 between marking R_3 and camera **104**. In an embodiment, data about time necessary for an optical signal to be reflected off each of markings R_1, R_2, and R_3 back to measurement system **100** is transmitted to memory **102** which is accessed by processor **101** to calculate distances D_1, D_2, and D_3 based on the data. In an alternative embodiment, data is transmitted from image acquisition module **104** directly to processor **101** for calculation of distances D_1, D_2, and D_3 and the results of the calculation is stored in memory **102**.

At step **206**, measurement system **100** determines angular orientation of object **110** in three-dimensional space. For example, a determination is made of a yaw angle ϕ and a pitch angle θ at which object **110** is positioned in three-dimensional space. The yaw angle ϕ is an angular displacement of object **110** relative to axes Y. Pitch angle θ is an angular displacement of object **110** relative to axes Z (as shown in FIG. **3**A). In an embodiment, determining of angular orientation of object **110** in three-dimensional space includes determining horizontal and vertical angles of object **110** with relative to measurement system **100**. FIG. **5** illustrates graphical representation of determining horizontal and vertical angles of object **110** in three-dimensional space. Specifically, horizontal and vertical angles for each marking of object **110** are determined by solving triangles **510** and **520** using the distance between each markings and the observed positions of R_1, R_2, and R_3 from the measurement system **100**. The Z coordinate for each marking R_1, R_2, and R_3 of object **110** is determined based on the determined vertical angles for each marking R_1, R_2, and R_3 and a determined slope distance from the measurement system **100** to R_2. FIG. **6** illustrates a graphical representation **600** of determining slope distance based on a top view of measurement system **100** and object **110**. The slope distance is determined based on known three-dimensional coordinates of a center **640** of measurement system **100**, known distances between markings R_1, R_2, and R_3, and the determined horizontal angles **620** and **630**.

Returning to FIG. **2**, at step **208**, based on the determined distances D_1, D_2, D_3, yaw angle ϕ, pitch angle θ, and three-dimensional coordinates of all markings R_1, R_2, and R_3, measurement system **100** determines a three-dimensional vector of object **110** by determining a best-fit line for markings R_1, R_2, and R_3.

At step **210**, based on known distances S_1, S_2, S_3 and based on the determined distances D_1, D_2, D_3, yaw angle ϕ, pitch angle θ, and the three-dimensional vector, measurement system **100** determines distance D_T to tip T and a location of tip T of object **110** in a three-dimensional space. In an embodiment, in the case that object **110** is in motion, continuous determining of distances D_1, D_2, D_3, yaw angle ϕ, and pitch angle θ of object **110** enables measurement system **100** to determine velocity of the object. Thus, measurement system **100** determines the instantaneous location of tip T of object **110** in a three-dimensional space and movement of object **110** in three-dimensional space with accuracy.

It is to be understood that measurement system **100** can be implemented as a part of a computing device configured to identify a location of tip T of object **110** in a three dimensional space. Alternatively, measurement system **100** can be communicatively connected to (wirelessly or via direct circuitry) and controlled by a computing device configured to identify a location of object **110** in a three dimensional space.

The foregoing Detailed Description is to be understood as being in every respect illustrative and exemplary, but not restrictive, and the scope of the invention disclosed herein is not to be determined from the Detailed Description, but rather from the claims as interpreted according to the full breadth permitted by the patent laws. It is to be understood that the embodiments shown and described herein are only illustrative of the principles of the present invention and that various modifications may be implemented by those skilled in the art without departing from the scope and spirit of the invention. Those skilled in the art could implement various other feature combinations without departing from the scope and spirit of the invention.

The invention claimed is:

1. A method of operation of a measurement system for identifying a location of a moving object having a tip end and a plurality of markings disposed on an outer surface in three-dimensional space, comprising:

acquiring an image of the moving object using a camera, the camera having a field of view that simultaneously captures both the moving object and at least three markings of the plurality of markings, each of the at least three markings having a known position on the moving object as measured from the tip end;

determining a distance between the measurement system and each of the at least three markings of the plurality of markings;

determining a plurality of angles at which the moving object is positioned in the three-dimensional space, the plurality of angles including at least a yaw angle and a pitch angle;

determining a three-dimensional vector of the object using the distance between the measurement system and each of the plurality of markings and using the

plurality of angles at which the moving object is positioned in the three-dimensional space; and

determining an instantaneous position of the tip end and a velocity of the moving object in the three-dimensional space based on the known position of each of the at least three markings on the object, the distance between each of the least three markings and the measurement system, the yaw angle, the pitch angle, and and the three-dimensional vector of the moving object.

2. The method of claim **1**, wherein each of the plurality of markings is a photo-reflector.

3. The method of claim **1**, wherein each of the plurality of markings is an optical signal emitter.

4. The method of claim **1**, wherein the plurality of markings is a combination of at least one photo-reflector and at least one optical signal emitter.

5. The method of claim **1**, wherein a distance between the tip end and at least one of the plurality of markings is known.

6. The method of claim **1**, wherein a distance between each of the plurality of markings is known.

7. The method of claim **1**, wherein determining a plurality of angles at which the moving object is positioned in the three-dimensional space comprises:

determining the yaw angle at which the moving object is positioned in the three-dimensional space; and

determining the pitch angle at which the moving object is positioned in the three-dimensional space.

8. The method of claim **1**, further comprising:

displaying to a user the position of the tip end of the moving object, a value of the distance to each of the plurality of markings, and the three-dimensional vector of the moving object.

9. The method of claim **1**, wherein determining the distance between the measurement system and each of the plurality of markings comprises:

measuring a plurality of distances between the measurement system and each of the plurality of markings to determine movement of the moving object.

10. An apparatus for identifying a location of a moving object having a tip end and a plurality of markings disposed on an outer surface in three-dimensional space, the apparatus comprising:

a camera, the camera having a field of view that simultaneously captures both the moving object and at least three markings of the plurality of markings, each of the at least three markings having a known position on the moving object as measured from the tip end;

an input-output module;

an antenna;

a storage device;

a processor; and

a memory communicatively couple with the processor, the memory storing computer program instructions which, when executed on the processor, cause the processor to perform operations comprising:

acquiring an image of the moving object using the camera;

determining a distance between the measurement system and each of the at least three markings of the plurality of markings;

determining a plurality of angles at which the moving object is positioned in the three-dimensional space, the plurality of angles including at least a yaw angle and a pitch angle;

determining a three-dimensional vector of the moving object using the distance between the measurement system and each of the plurality of markings and using the plurality of angles at which the moving object is positioned in the three-dimensional space; and

determining an instantaneous position of the tip end and a velocity of the moving object in the three-dimensional space based on the known position of each of the at least three markings on the moving object, the distance between each of the at least three markings and the measurements system, the yaw angle, the pitch angle, and the three-dimensional vector of the moving object.

11. The apparatus of claim **10**, wherein the image-acquiring module comprises a Charge-Coupled Device (CCD) camera.

12. The apparatus of claim **10**, wherein determining a plurality of angles at which the moving object is positioned in the three-dimensional space comprises:

determining the yaw angle at which the moving object is positioned in the three-dimensional space; and

determining the pitch angle at which the moving object is positioned in the three-dimensional space.

13. The apparatus of claim **10**, the operations further comprising:

displaying to a user the position of the tip end of the moving object, a value of the distance to each of the plurality of markings, and the three-dimensional vector of the moving object.

14. The apparatus of claim **10**, wherein determining the distance between the measurement system and each of the plurality of markings comprises:

measuring a plurality of distances between the measurement system and each of the plurality of markings to determine movement of the moving object.

15. A non-transitory computer-readable medium storing computer program instructions for identifying a location of a moving object having a tip end and a plurality of markings disposed on an outer surface in three-dimensional space, which, when executed on a processor, cause the processor to perform operations comprising:

acquiring an image of the object using a camera, the camera having a field of view that simultaneously captures both the moving object and at least three markings of the plurality of markings therein, each of the at least three markings having a known position on the moving object as measured from the tip end;

determining a distance between the measurement system and each of the at least three markings of the plurality of markings;

determining a plurality of angles at which the moving object is positioned in the three-dimensional space, the plurality of angles including at least a yaw angle and a pitch angle;

determining a three-dimensional vector of the moving object using the distance between the measurement system and each of the plurality of markings and using the plurality of angles at which the moving object is positioned in the three-dimensional space; and

determining an instantaneous position of the tip end and a velocity of the moving object in the three-dimensional space based on the known position of each of the at least three markings on the object, the distance between each of the at least three markings and the measurement system, the yaw angle, the pitch angle, and the three-dimensional vector of the moving object.

16. The non-transitory computer-readable medium of claim **15**, wherein determining a plurality of angles at which the moving object is positioned in the three-dimensional space comprises:

determining the yaw angle at which the object is positioned in the three-dimensional space; and

determining the pitch angle at which the object is positioned in the three-dimensional space.

17. The non-transitory computer-readable medium of claim **15**, the operations further comprising:

displaying to a user the position of the tip end of the object, a value of the distance to each of the plurality of markings, and the three-dimensional vector of the object.

18. The non-transitory computer-readable medium of claim **15**, wherein the determining the distance between the measurement system and each of the plurality of markings comprises:

measuring a plurality of distances between the measurement system and each of the plurality of markings to determine movement of the moving object.

19. An apparatus for identifying a location of a moving object having a tip end and a plurality of markings disposed on an outer surface in three-dimensional space, the apparatus comprising:

means for acquiring an image of the moving object, the means for acquiring the image having a field of view that simultaneously captures both the moving object and at least three markings of the plurality of markings, each of the at least three markings having a known position on the moving object as measured from the tip end;

means for determining a distance between the measurement system and each of the at least three markings of the plurality of markings;

means for determining a plurality of angles at which the moving object is positioned in the three-dimensional space, the plurality of angles including at least a yaw angle and a pitch angle;

means for determining a three-dimensional vector of the moving object using the distance between the measurement system and each of the plurality of markings and using the plurality of angles at which the moving object is positioned in the three-dimensional space; and

means for determining an instantaneous position of the tip end and the velocity of the moving object in the three-dimensional space based on the known position of each of the at least three markings on the object, the distance between each of the at least three markings and the measurement system, the yaw angle, the pitch angle, and the three-dimensional vector of the moving object.

20. The apparatus of claim **19**, the apparatus further comprising:

means for displaying to a user the position of the tip end of the moving object, a value of the distance to each of the plurality of markings, and the three-dimensional vector of the moving object.

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